Climate change effects on California's marine resources

Richard F. Ambrose
Department of Environmental Health Sciences
Environmental Science and Engineering Program
Institute of the Environment and Sustainability

Climate change effects

- Water and air temperature
- Ocean acidification
- Ocean deoxygenation (Hypoxia)
- Sea level rise

Water and air temperature

- Phenology (seasonal activities)
- Distributions
  - As in terrestrial ecosystems, generally poleward shifts expected
  - But complicated for rocky intertidal
- Biodiversity
- Abundances
  - Changes in ocean productivity
  - Food web consequences
- Harmful Algal Blooms
- Disease

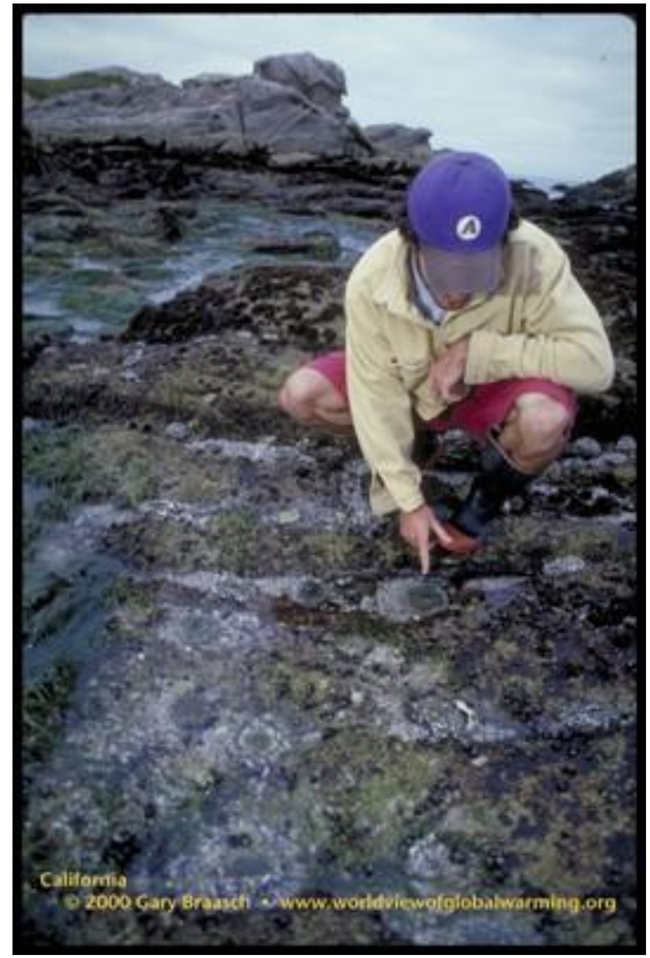
Distributions

- Poleward shift in species ranges
  - The range and abundance of warm-water species are increasing, whilst those of coldwater species are diminishing
- Zonation patterns influenced by both air and sea temperatures
  - Reduced recruitment of fucoids and intertidal invertebrates in the littoral zone due to rising temperatures causing desiccation of propagules and suppressing growth leaving new recruits more susceptible to grazers
- Decline of kelp ecosystems with rising sea surface temperature

Hoegh-Guldberg and Bruno 2010

Rocky intertidal organisms: Changes in distributions

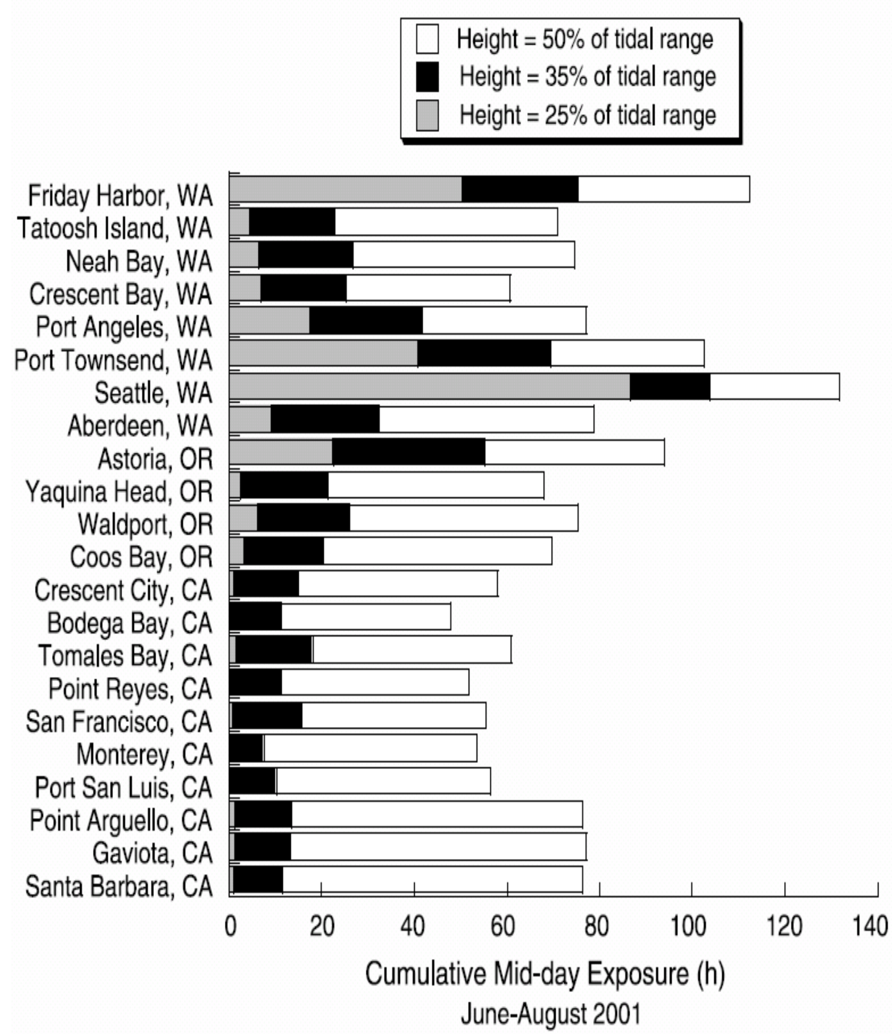
- Changes in invertebrate species in Monterey Bay such as limpets, snails, and sea stars in the 60-year period between 1931-1933 and 1993-1994 indicate that species' ranges are shifting northwards
  - Probably in response to warmer ocean and air temperatures



Barry et al. 1995, Sagarin et al. 1999

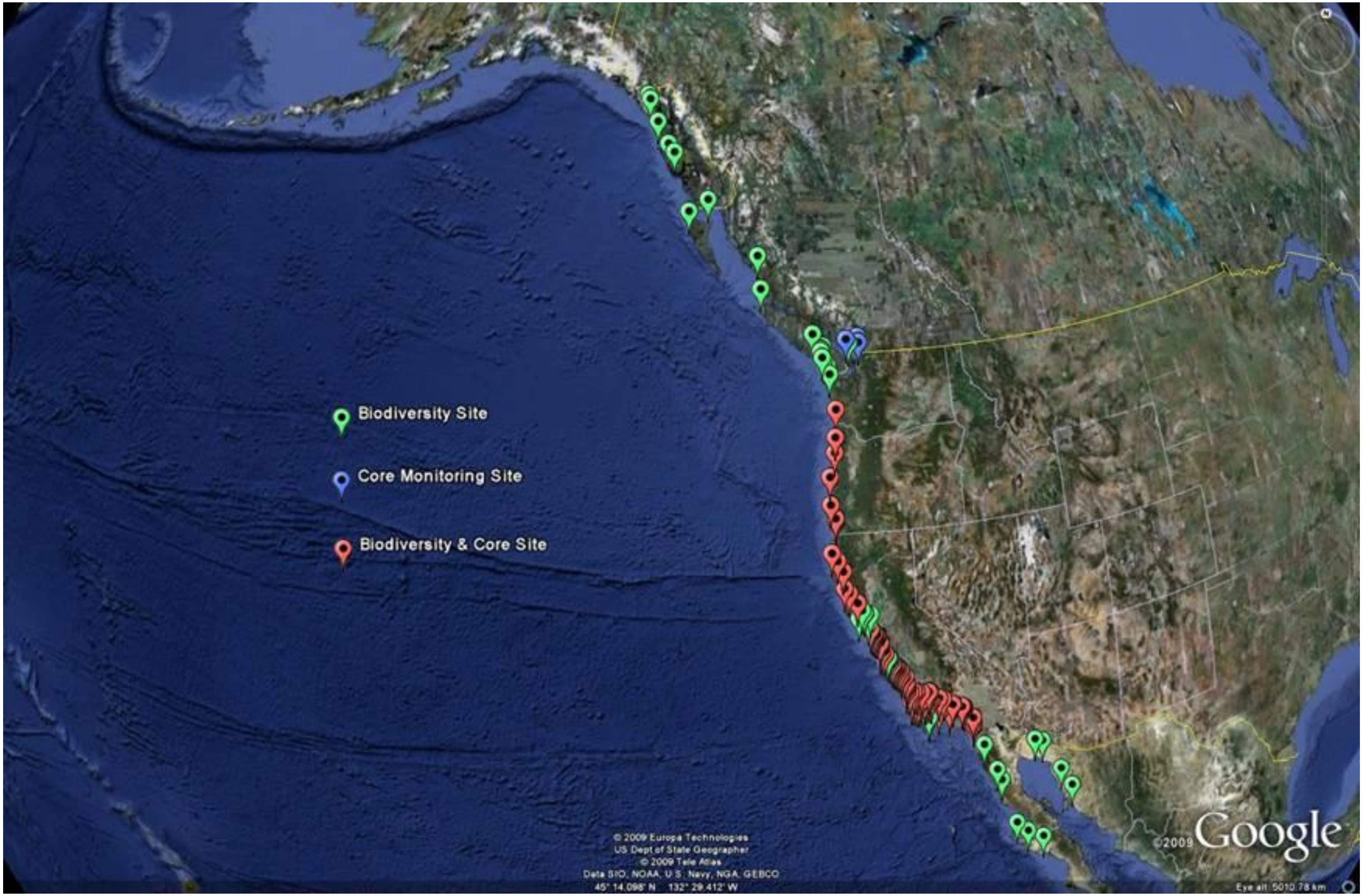
Timing of low tides important

- Helmuth has shown that timing of low tides leads to a complex mosaic of thermal environments
- Distributional changes may not be simply poleward
  - May get localized extinctions at “hot spots”
- Need local measurements of environmental conditions



The three tidal heights shown roughly correspond to the tidal heights of mussel beds. Variability among sites is most pronounced at low intertidal heights. Helmuth et al. (2002)

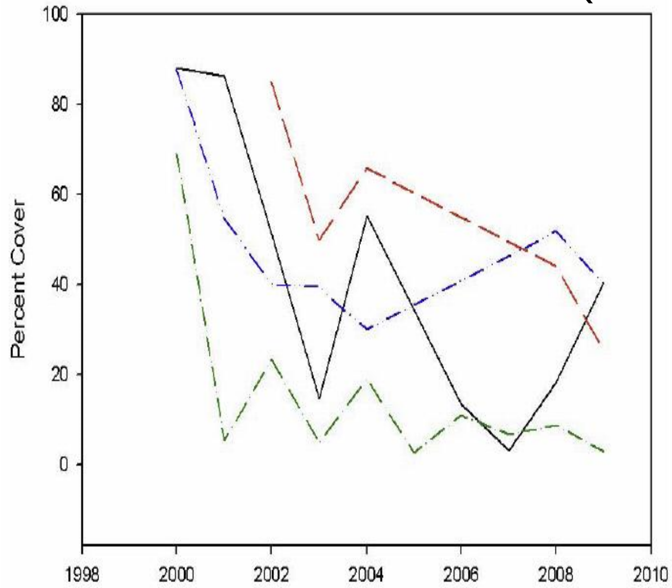
Multi-Agency Rocky Intertidal Network MARINe



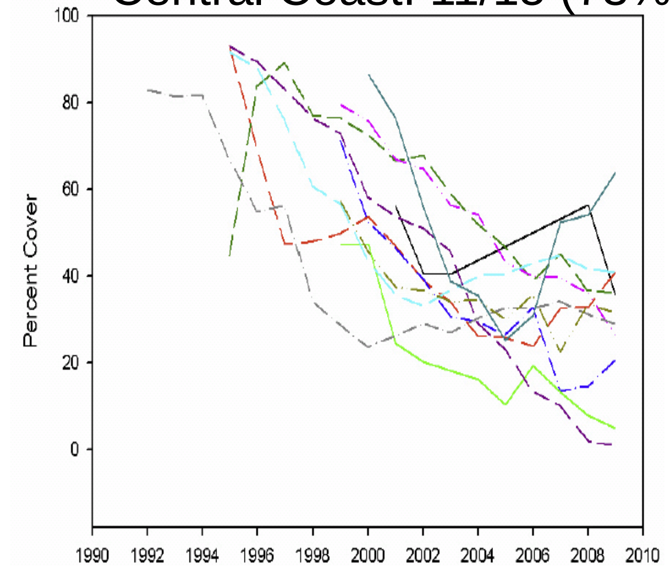
Declines in rockweed abundances

Declines in rockweed abundances

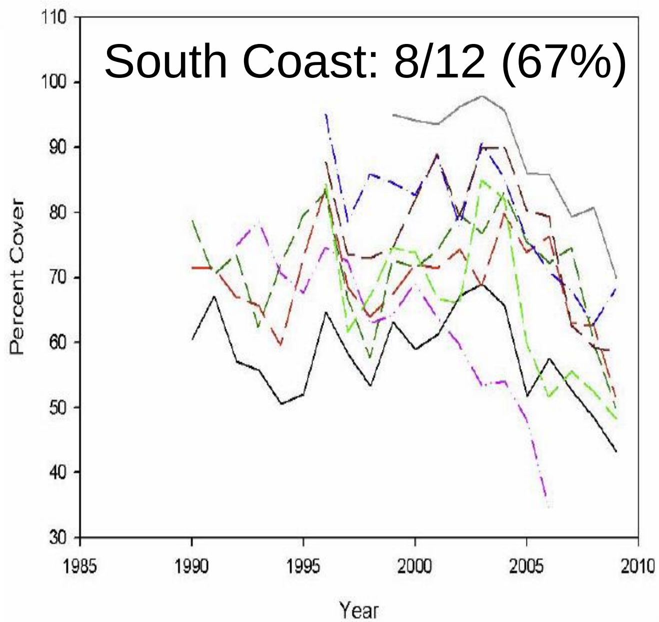
Pacific Northwest: 4/8 (50%)



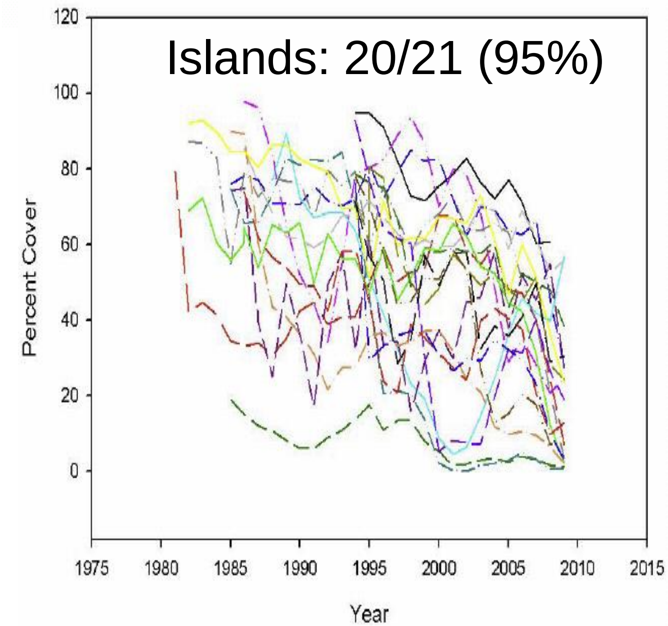
Central Coast: 11/15 (73%)



South Coast: 8/12 (67%)

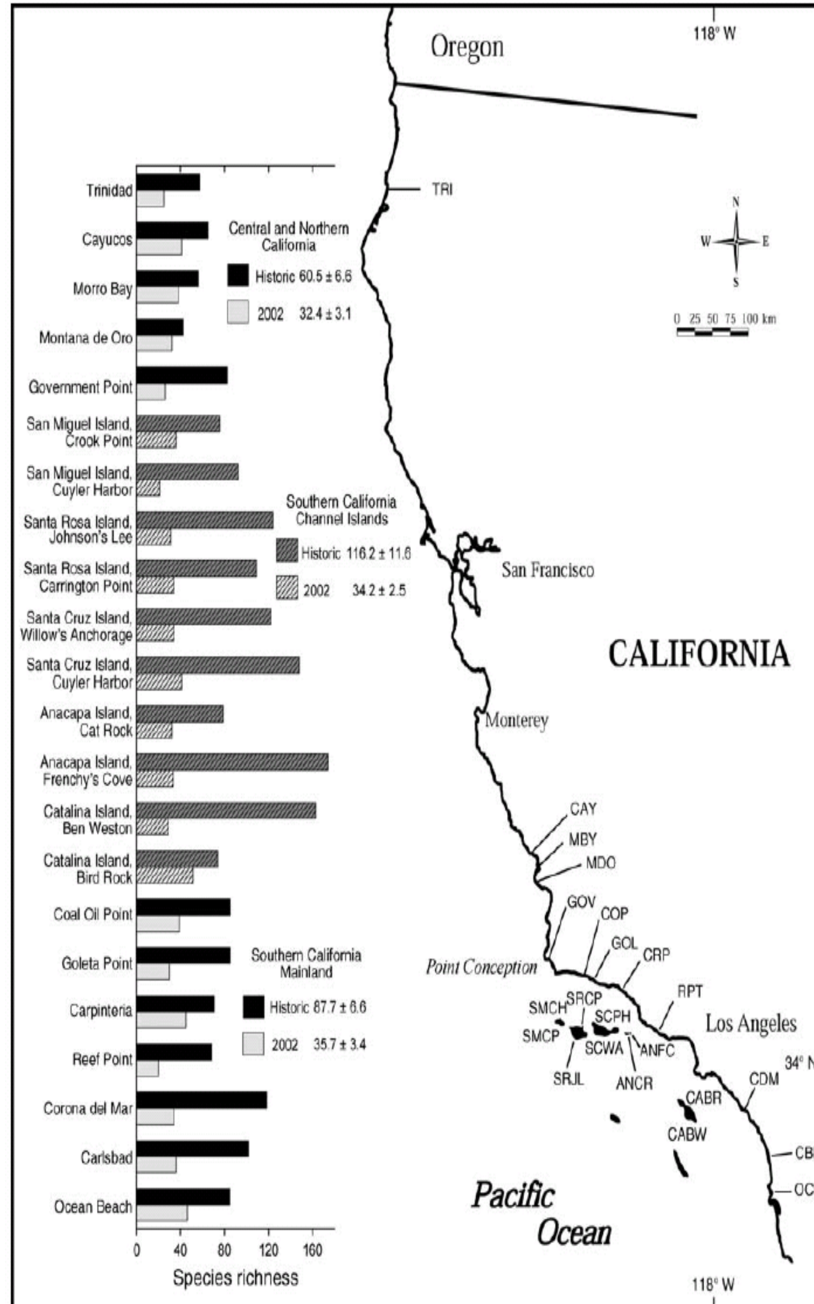


Islands: 20/21 (95%)



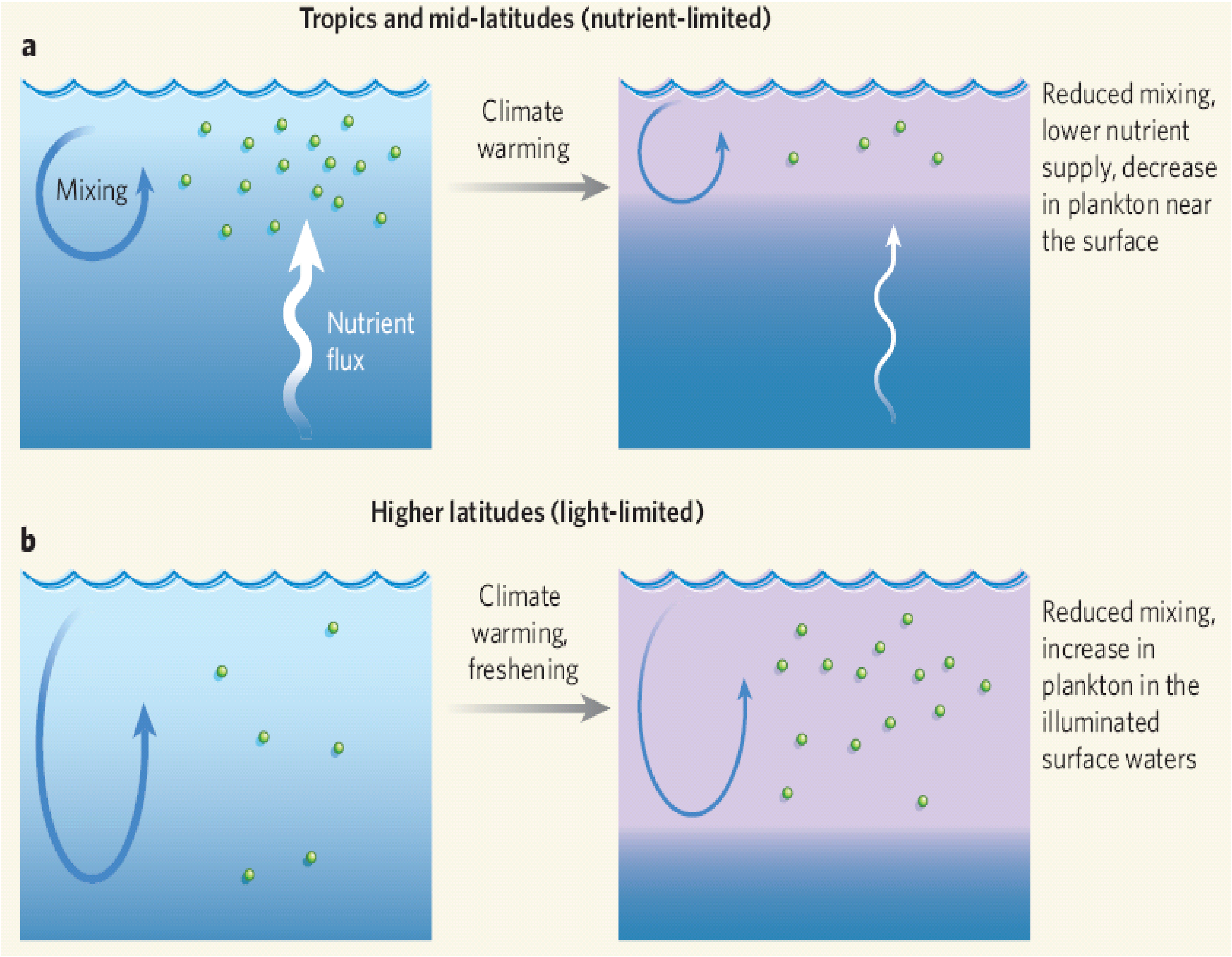
Changes in biodiversity

- Large declines in community associated with mussel beds
  - Overall decline 59%
  - Southern California Channel Islands decline 70%
  - Southern California mainland decline 59%
- Loss of many rare species
- Biodiversity related to ocean productivity, climate



Smith, Fong and Ambrose. 1999. Ecology.

Warming, mixing and productivity



Doney 2006

Zooplankton in the Southern California Bight

- Biomass decreased by 80% (1951-93)
- Surface temperature warmed
  - Water column became more stratified
- Likely ecosystem wide effects

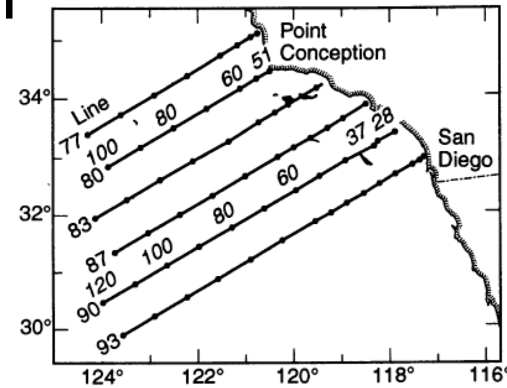


Fig. 1. CalCOFI survey plan, with station numbers (italics) indicated on lines 80 and 90.

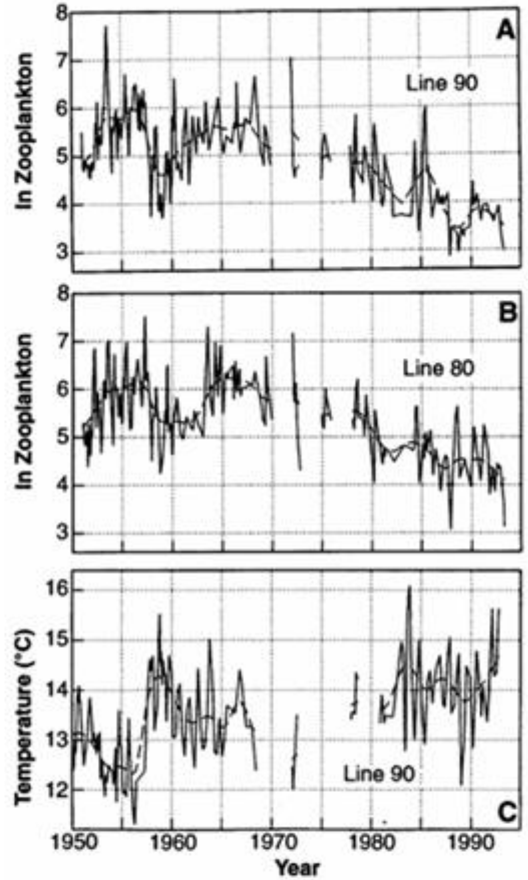
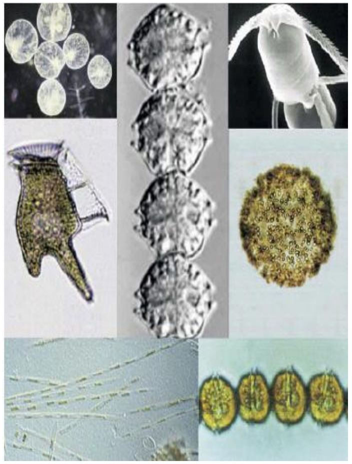


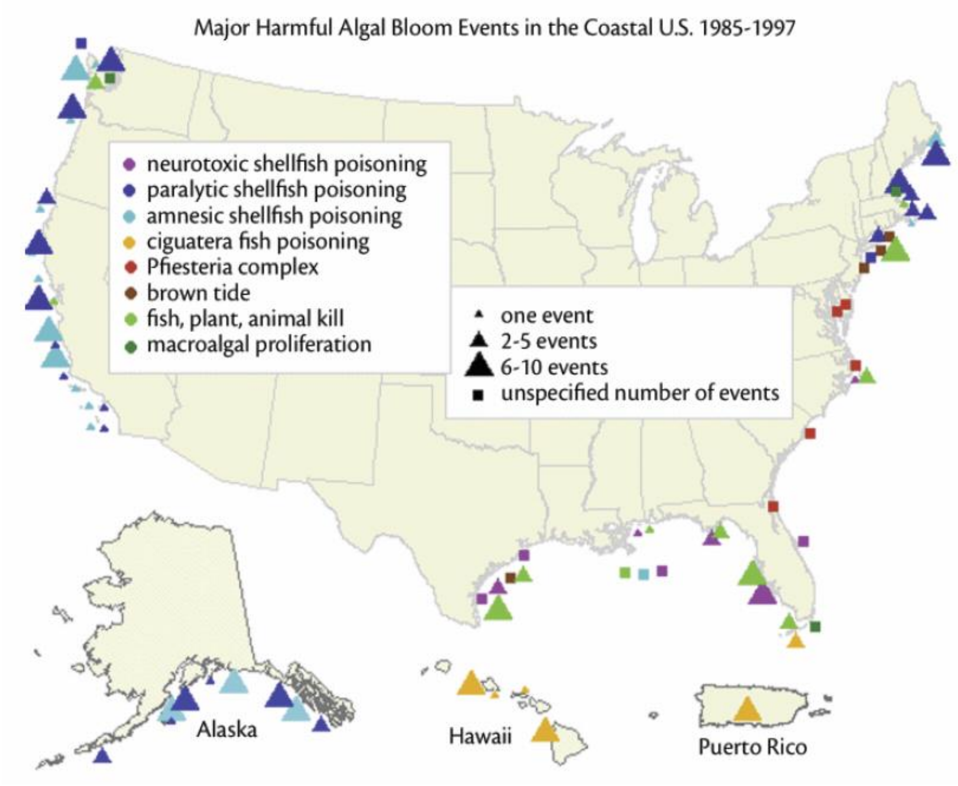
Fig. 2. Time series of log-transformed zooplankton volume (cubic centimeters of zooplankton volume per 1000 m^3 of seawater strained) for (**A**) line 90 and (**B**) line 80. On the logarithmic scale, a change of −1.6—which in (A) and (B) is the change from the mean of the 1950–1970 data to the minimum in the 1990s—is equivalent to an 80% decrease. (**C**) Time series of the upper 100 m average temperature for line 90.

Roemmich and McGowan 1995

Harmful Algal Blooms (HABs)

- Some evidence of more HABs with warmer water
  - Algae forming HABs may be favored in warmer ocean

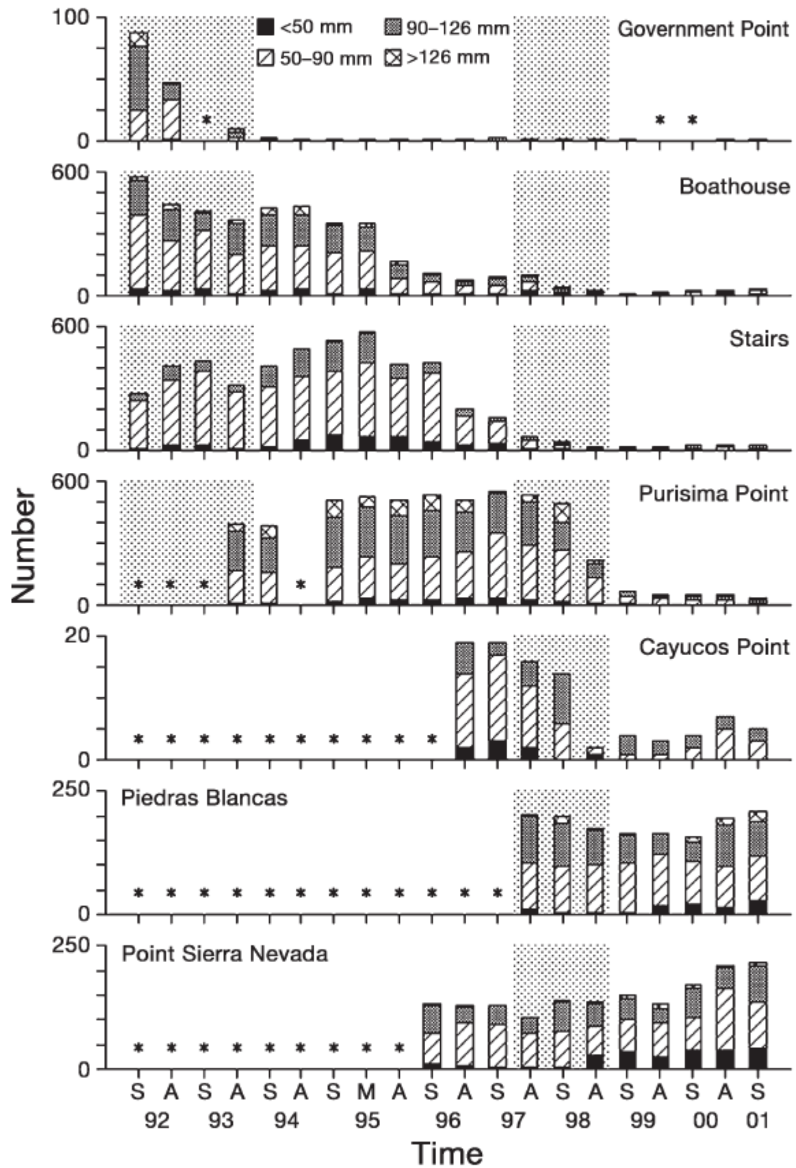




Peperzak 2003, Edwards et al. 2006, Gilbert et al. 2005

Disease

- More disease expected
  - Changing distributions of pathogens and vectors
  - Increased susceptibility due to environmental stress
- Example: black abalone “withering syndrome”
  - First noticed at CINP
  - MARINe monitoring demonstrated progression up coast
  - Related to warming water



Raimondi et al. 2002

Effects of ocean acidification

- Direct impacts on organisms that form a $CaCO_3$ shell or skeleton
  - Photosynthetic plankton (coccolithophores, foraminifera, and euthecosomatous pteropods), shellfish and other molluscs, echinoderms, corals, coralline algae
  - Unable to form shell, or extra energy to form shell could reduce growth and survival
  - Larvae may be particularly sensitive
- Effects on marine food webs
  - Losses of plankton, juvenile shellfish, and other organisms at the bottom of marine food chains have the potential to reduce harvests of economically important species
  - Predators may switch to other species, such as juvenile salmon
  - Loss of important ecosystem engineers (mussels and oysters)

Expected vulnerability of marine flora and fauna to ocean acidification

	Vulnerability	Level of Understanding	Comment	References
Diatoms	Low	High	Increased productivity, smaller or larger chain-forming species (?)	Tortell et al., 1997, 2008; Hare et al., 2007
Coccolithophorid	Medium	Low	Species specific response in calcification, increased photosynthesis	Iglesias-Rodriguez et al., 2008; Engel et al., 2005
Kelp	Medium	Medium	Species specific response in photosynthesis	Swanson and Fox, 2007
Copepods	Medium	Low	Shallow water copepods showed less tolerance to high pCO_2 than deep water copepods	Watanabe et al., 2006
Noncalcifying tunicate	Low	Medium	Increased growth, development, and fecundity	Dupont and Thorndyke, 2009
Shelled pteropod	High	Low	Shell dissolution	Orr et al., 2005; Fabry et al., 2008
Foraminifera	High	Medium	8–14% reduction in shell mass	Spero et al., 1997; Bijma et al., 1999, 2002; Moy et al., 2009
Sea urchin	Medium	Medium	Species specific, lack of pH regulation, decreased fertilization success	Burnett et al., 2002; Dupont and Thorndyke, 2008
Mussel	High	High	Decreased calcification in saturated water; dissolution and mortality in undersaturated water	Gazeau et al., 2007
Oyster	Medium	High	Decrease in calcification rate, highly vulnerable larval stage	Gazeau et al., 2007; Lee et al., 2006
Dungeness crab	Low	Low	Capable of pH regulation during 24 h	Pane and Barry, 2007
Cold water corals	High	Low	Experimental results only for warm water corals	Guinotte and Fabry, 2008
Coralline algae	High	Medium	Decrease in calcification rate, net dissolution, disappearance	Martin and Gattuso, 2009

Hauri et al. 2009, adapted from Fabry et al. 2008

Effects of ocean acidification on California aquaculture

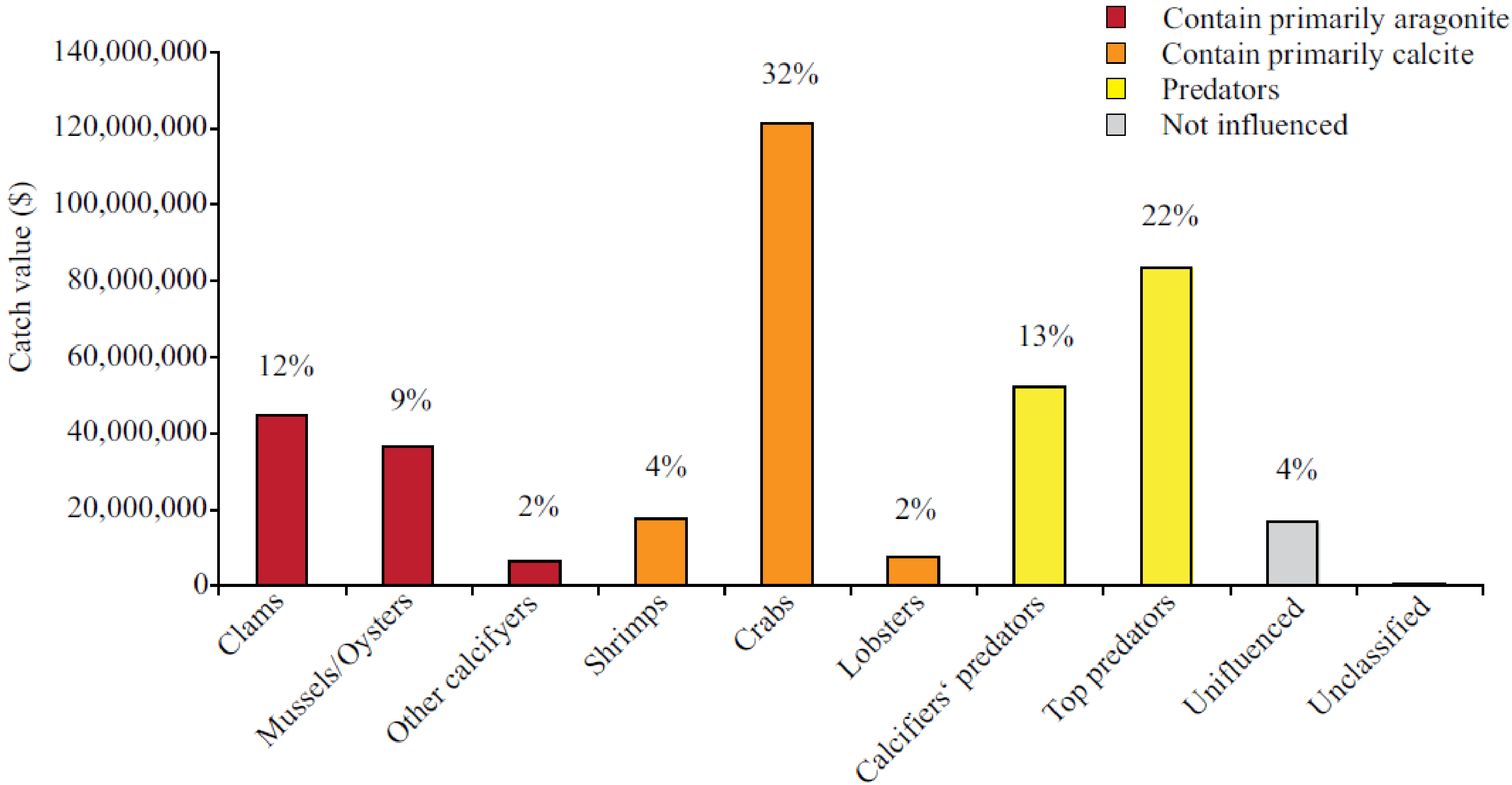


Figure 5. US West Coast commercial fishing ex-vessel revenue (the price paid at the time the fish are delivered by the commercial fisherman to the fish receiver or processor) for 2007 (adapted from Cooley and Doney, 2009, using NOAA National Marine Fisheries Service statistics), including California, Oregon, Washington, and Pacific, and at sea. Colors indicate which form (if any) of calcium carbonate these groups contain. Based on present understanding, organisms containing aragonite are most likely to be affected by ocean acidification.

Hauri et al. 2009

UC Ocean Acidification Consortium

As the need to forecast the impacts of ocean acidification on marine ecosystems has become more urgent, it is clear that sound science and contributions to strategies will only be found through multidisciplinary collaborations within the broad marine science community.

The UC Ocean Acidification Consortium represents scientists from across the University of California system working to integrate and strengthen our research programs to work on critical questions about how ocean acidification will impact marine communities. We are focused on designing and implementing multidisciplinary training for graduate students and postdoctoral fellows, with major budgetary allocations for traineeship support. These efforts will position UC as a national center for the study of ocean acidification, and train the next generation of scientists contributing to knowledge on ocean acidification and impacts on the California coast.

UC Santa Barbara

- Gretchen Hofmann - ecology/phsyiology
- Libe Washburn - oceanography
- Mark Brzezinski - phytoplankton ecology and physiology
- Craig Carlson - microbial ecology/biogeochemistry
- Uta Passow - biological oceanography

UC Davis

- Brian Gaylord - ecology
- Tessa Hill - biogeochemistry
- Ann Russell - chemical oceanography
- Eric Sanford - ecology/physiology

UC San Diego

- Andrew Dickson - biogeochemistry
- Todd Martz - biogeochemistry/instrumentation
- Jennifer Smith - ecology

Ocean deoxygenation

- Low oxygen zones seem to be increasing
  - Gulf of Mexico “Dead Zone” best known
  - Most anthropogenic hypoxia zones related to increased nutrient input, but may see increase ocean deoxygenation
- Recent expansion of hypoxic zone into shallow water off Oregon and Washington
- Mass die-offs of fish and invertebrates

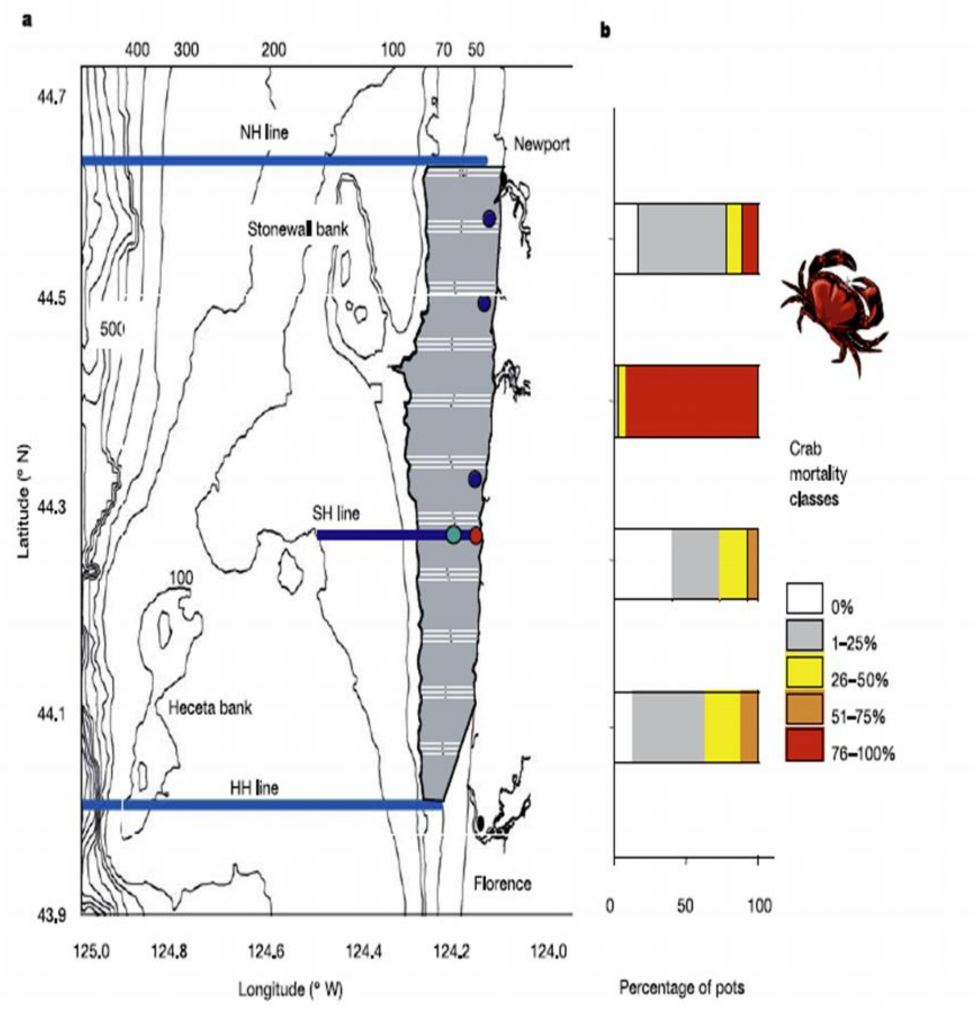
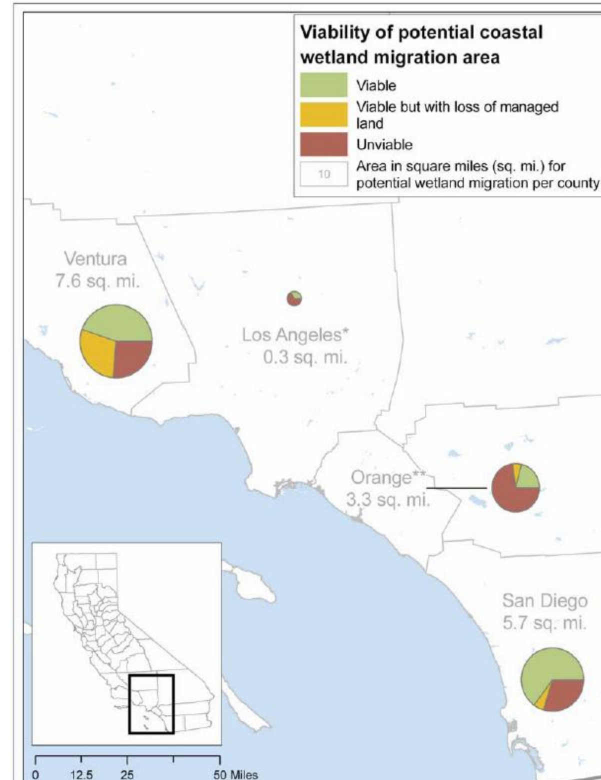


Figure 1 Location of the 2002 hypoxic zone and hydrographic transects off Oregon. **a**, Annual ROV patch reef surveys (green circle). Additional hydrographic stations (blue circles) and the acoustic Doppler current profiler (ADCP) location (red) are indicated. The minimum estimated spatial extent of the severe hypoxic zone over the inner shelf (~820 km^2) is shown (grey). **b**, Proportional mortality of crabs (sampled 16, 17 July 2002) among 80 crab pots deployed within four regions of the hypoxia zone.

Grantham et al. 2004.

Sea level rise

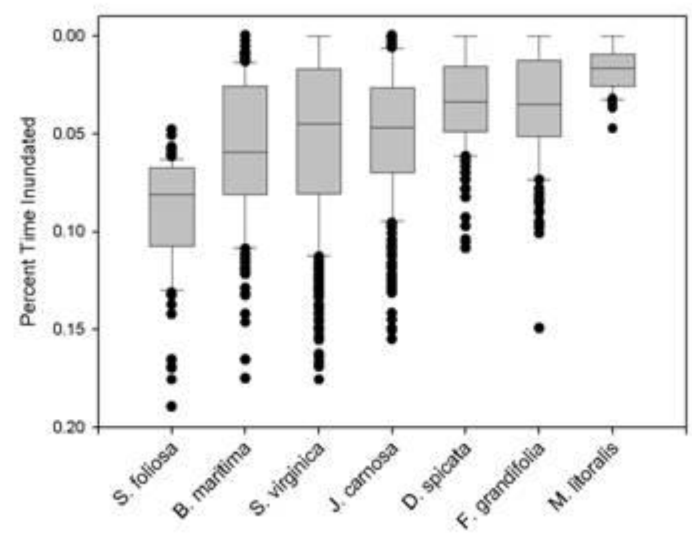
- Effects on wetlands
  - Marshes may be able to keep up with SLR if they have sufficient sediment
  - Habitat composition likely to change – more subtidal and mudflats
  - Generally little opportunity to migrate landward
- Effects on rocky intertidal
  - Generally little opportunity to migrate landward



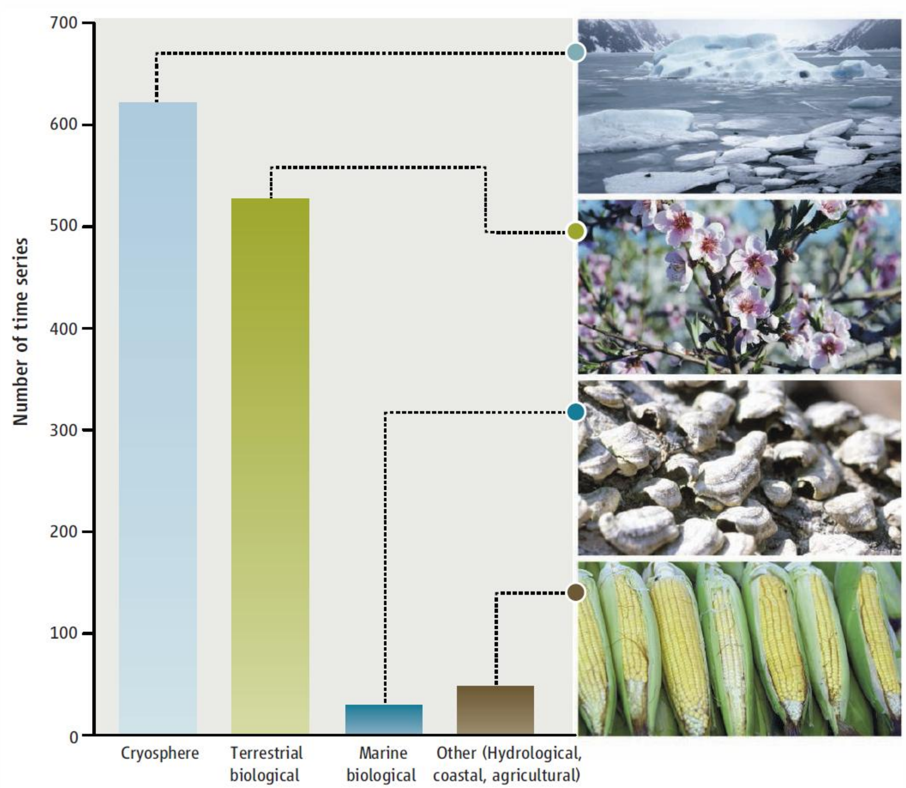
Viability of potential coastal wetland migration area in response to a 1.4 meter sea-level rise in Southern California

* 23% of Los Angeles County coastline mapped. ** 65% of Orange County coastline mapped.
Data sources: USGS/Scripps Institution of Oceanography, NOAA Coastal Change Assessment Program.
http://www.pacinst.org/reports/sea_level_rise

PACIFIC INSTITUTE

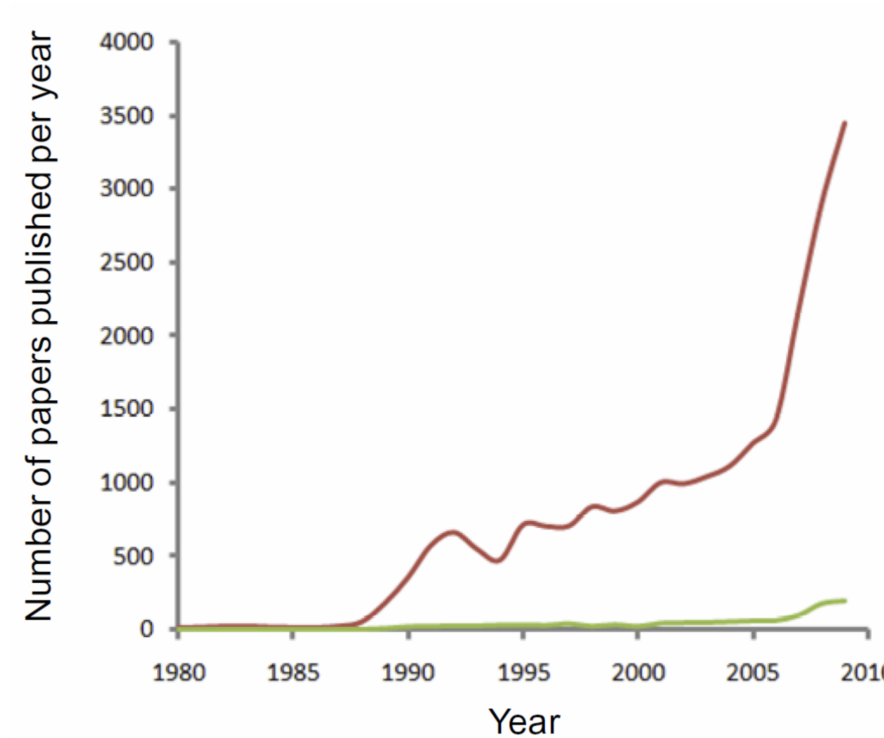


Marine ecosystems are understudied



Marine undersampling. The number of time series from different environments included in the recent IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report differ widely. Marine systems are vastly underrepresented compared with terrestrial systems (*1*).

The number of time series from different environments included in the IPCC Fourth Assessment Report differ widely. Marine systems are vastly underrepresented compared with terrestrial systems. (Richardson and Poloczanska 2008)



Yearly publication rates (1980-2009) of studies with “climate change”, “global warming” or “ocean acidification” in the title (Red line) versus publications with the same title words but combined with “marine”, “ocean”, “sea”, or estuary”. (Hoegh-Guldberg and Bruno 2010)

Conclusions

- Like terrestrial ecosystems, marine species will respond to climate change with changes in phenology, distributions and abundances
  – Novel community composition expected
- In contrast to terrestrial ecosystems, fundamental changes in primary production are expected, with widespread ramifications
  – Changes in stratification and upwelling
  – Ocean acidification
- Climate change effects are poorly understood in marine ecosystems compared to terrestrial ecosystems

Key publications

- Hoegh-Guldberg and Bruno. 2010. The Impact of Climate Change on the World's Marine Ecosystems. Science 328: 1523-1528.
- Harley, C. D. G., et al. 2006. The impacts of climate change in coastal marine systems. Ecology Letters 9: 228-241.
- PRBO Conservation Science. 2011. Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife. Version 1.0. http://data.prbo.org/apps/bssc/climatechange